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**Louderback**

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(54) **OPTICAL BENCH APPARATUS HAVING INTEGRATED MONITOR PHOTODETECTORS AND METHOD FOR MONITORING OPTICAL POWER USING SAME**

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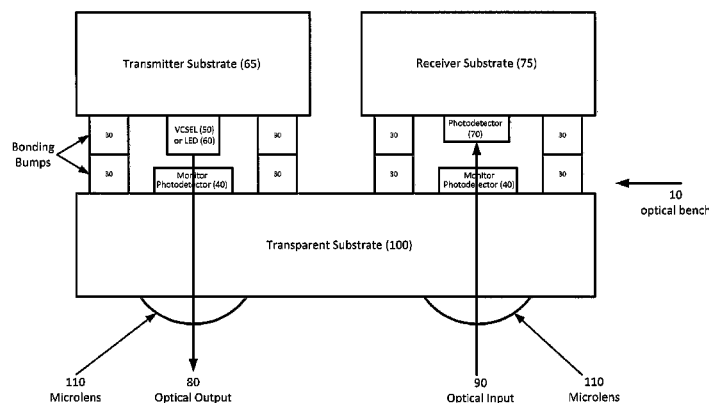
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(57) **ABSTRACT**

Optical bench structure provides a platform for integrating optical transmitters, particularly Vertical-Cavity Surface-Emitting Lasers (VCSELs), with monitor photodetectors. A substrate with photodetectors on the front side is aligned with flip-chip bonding bumps so the emission of the transmitters is aligned with the monitor photodetectors and passes through the monitor photodetectors with a portion of the transmitted light absorbed by the monitor photodetectors. The photodetectors have a thin absorption region so the percentage of light absorbed may be relatively small, providing sufficient photocurrent to monitor the transmitted power having a minimal effect on the transmitted power. Microlenses are integrated on the backside of the substrate focus, steer and/or collimate the emitted optical beams from the transmitters. The structure enables photodetectors to be integrated on the optical bench allowing the received optical power to be monitored. The receiver photodetectors are integrated on the optical bench alone and/or in combination with the transmitters.

**30 Claims, 3 Drawing Sheets**



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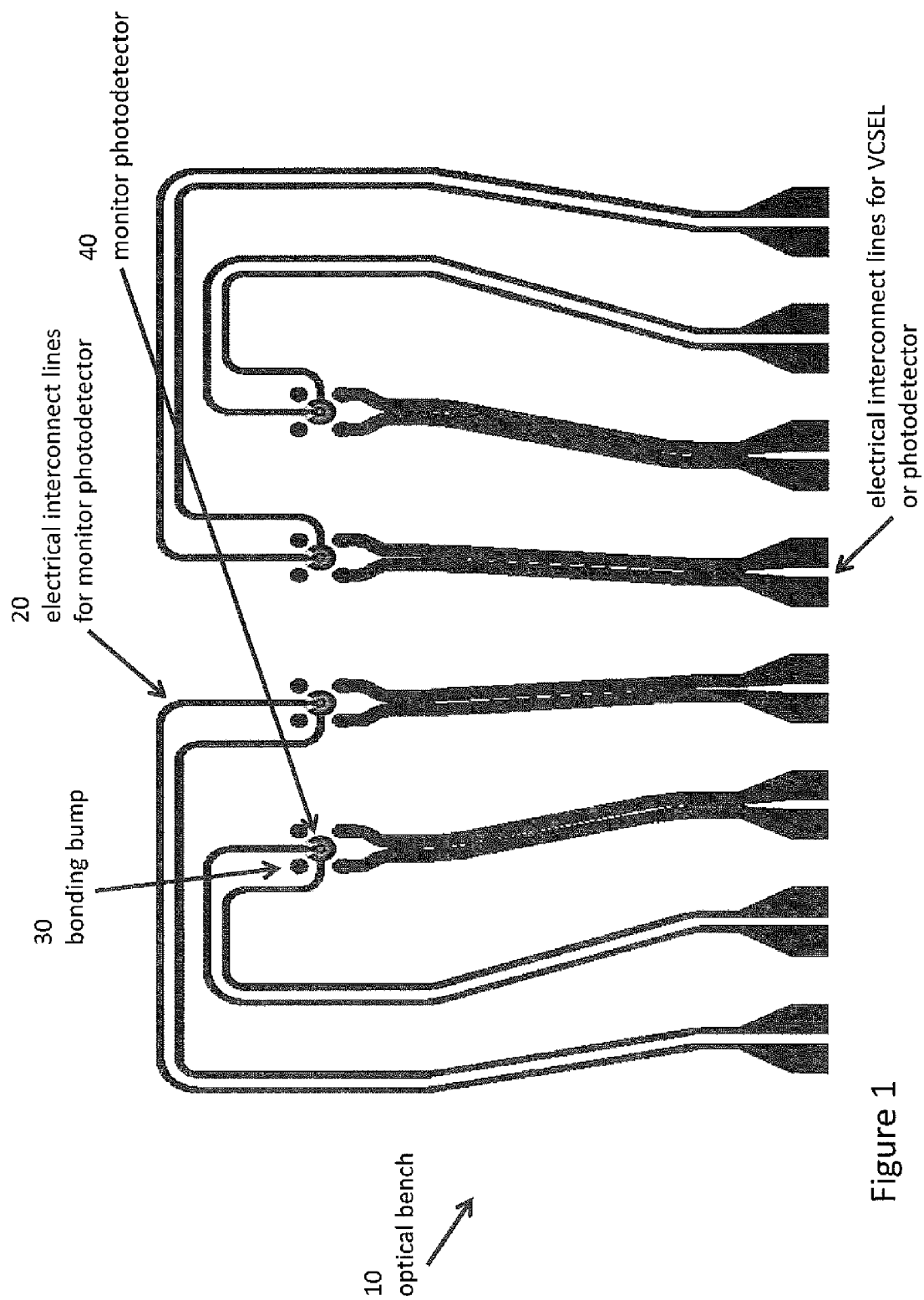


Figure 1

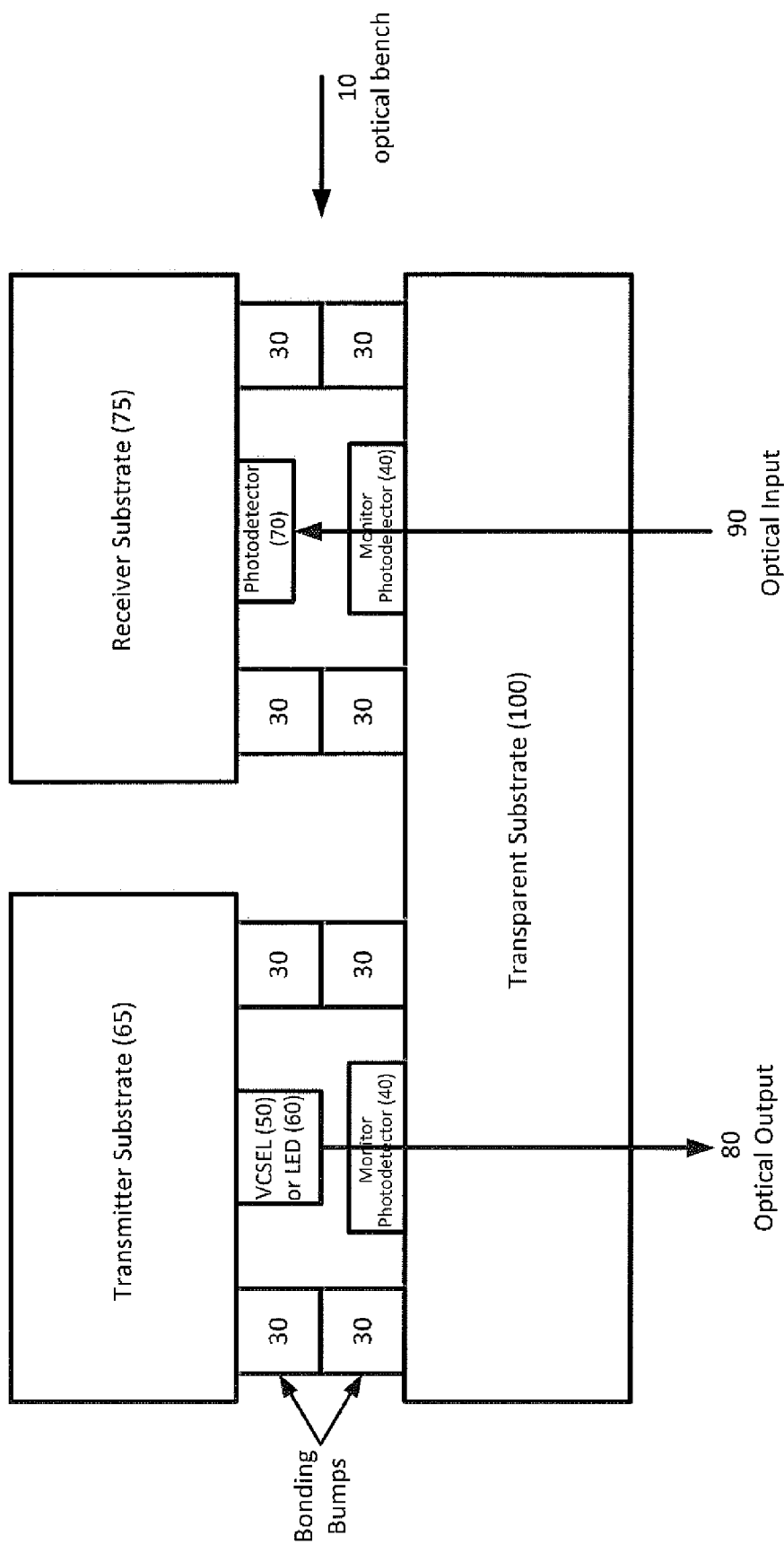


Figure 2

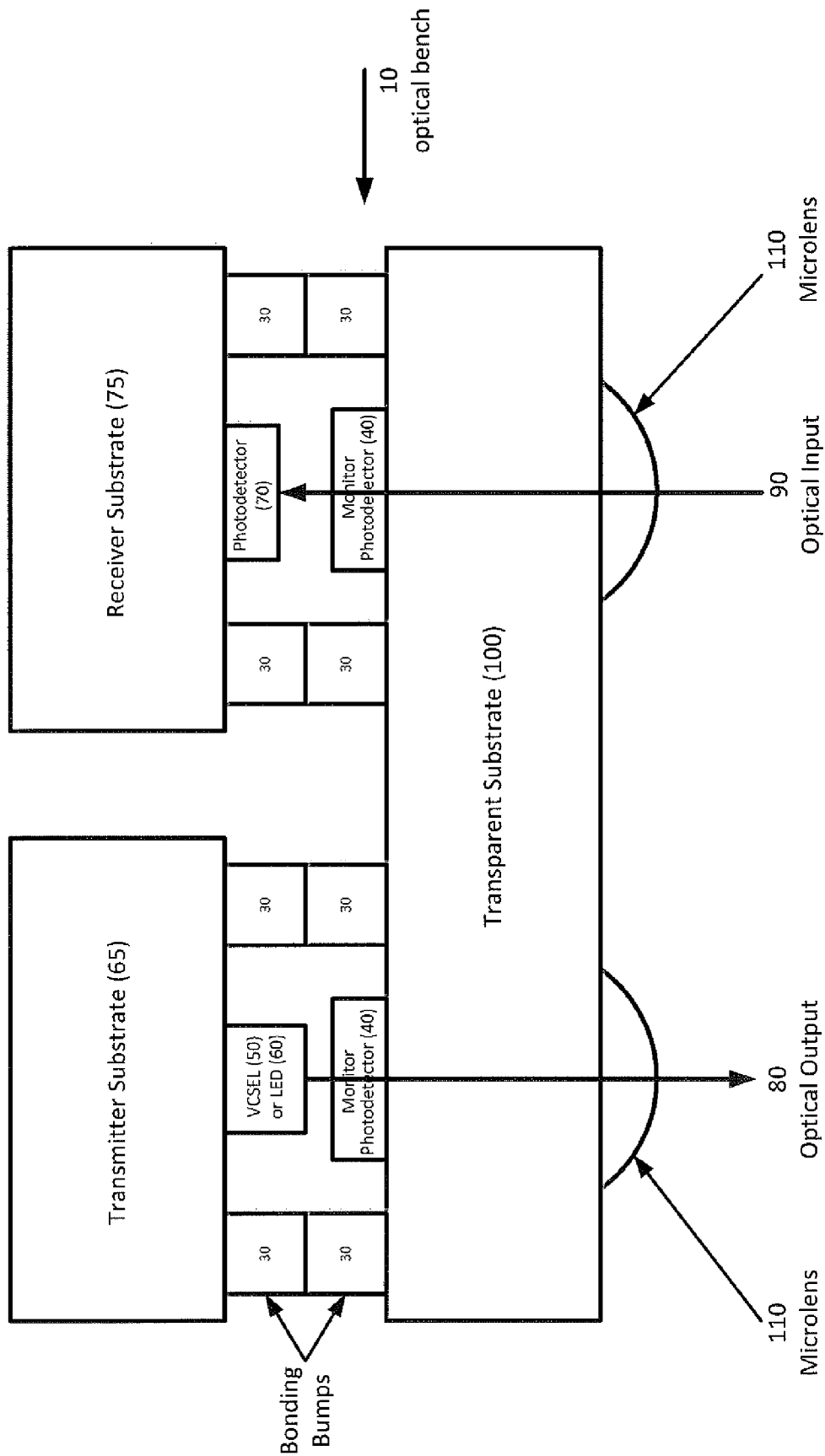


Figure 3

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**OPTICAL BENCH APPARATUS HAVING  
INTEGRATED MONITOR  
PHOTODETECTORS AND METHOD FOR  
MONITORING OPTICAL POWER USING  
SAME**

This application is a continuation of, and claims priority and benefits of, U.S. patent application Ser. No. 14/133,154 filed Dec. 18, 2013, which further claims the benefit of U.S. Provisional Application Ser. No. 61/747,415 entitled "Optical Bench Apparatus and Method" filed Dec. 31, 2012, the entire content of which is hereby incorporated by reference in its entirety.

**BACKGROUND OF THE INVENTION**

This invention relates generally to optical power monitoring. In particular, the invention relates specifically to an optical bench apparatus having integrated monitor photodetectors and a method for monitoring optical power using the optical bench apparatus for optical power monitoring in optical modules. Monitoring the level of optical power emitted by transmitters may be a highly desirable feature in many optical modules, especially optical transceivers. Monitoring the optical power may allow the bias and/or modulation currents to be optimized to achieve the desired operating characteristics of both the transmitter itself, as well as the entire optical link. Such optimization of the bias and/or modulation currents may allow operating characteristics to be adjusted for temperature variations and/or degradation due to aging, optical alignment and/or other environmental factors. Monitoring the transmitted power and/or received power in an optical link may enable health monitoring and/or functions to be implemented in the transceiver. Further, monitoring the transmitted power and/or received power in an optical link may also enable built-in test functions to be implemented in the transceiver.

Optical power monitoring of transmitters has been implemented by various methods. One such method of optical power monitoring may create a back-reflection in the optical package and utilize this back-reflection to monitor the optical power. For example, U.S. Pat. No. 5,757,836 discloses TO-can-based transmitter optical subassemblies (TO-SAs) that may implement such a method of optical power monitoring. A cap on the TO-can may provide a small back-reflection that may then be detected by a monitor photodetector placed either next to the transmitting devices and/or underneath the transmitting devices such that the cap of the TO-can may extend laterally beyond the extent of the transmitter die. The TO-can-based method has been acceptably implemented but may be best-suited to modules with a small number of transmitters. Further, the method may not scale well to parallel modules with a small form factor.

Another method and/or approach to optical power monitoring may utilize back-side emission of a transmitting device. Although such a method may be possible with a Vertical-Cavity Surface-Emitting Laser (VCSEL), implementation with an in-plane laser in which emission from the back facet may be exploited to monitor the power emission from the laser may be more feasible and/or effective. An example of this method and/or approach may be implemented with a 622 Mb/s Logic Interface DFB Laser Transmitter manufactured by Hewlett Packard. The technical specifications and other information for such a device may be found on the Internet in <http://www.datasheetcatalog.org/datasheet/hp/XMT5170B-622-AP.pdf>. This method and/or approach to optical power monitoring may be implemented

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in many different ways. For example, such a method of optical power monitoring may be monolithically integrated and/or heterogeneously integrated. A fundamental approach in such methods and/or approaches may use a transmission out of the back facet. The power of the back facet transmission may be a known ratio of the power out of the front facet. The front facet power may be used for the transmitter in the optical module, while the back facet power may be absorbed by a monitor photodetector to provide the power monitoring.

Various substrates have also been utilized as optical benches for integrating transmitters and/or photodetectors. Some of these optical benches have included backside microlenses formed by a variety of techniques. For example, such microlenses are disclosed in "Parallel Free-Space Optical Interconnects Based on Arrays of Vertical-Cavity Lasers and Detectors with Monolithic Microlenses," Eva M. Strzelecka, et al., volume 37, issue 14, pp. 2811-2821, 1998.

**SUMMARY OF THE INVENTION**

In an embodiment of the present invention, an optical bench apparatus is provided. The optical bench apparatus may have a transparent substrate with electrical interconnect lines and/or pads for attaching transmitters and/or receivers by flip-chip bonding. Monitor photodetectors may be aligned to these bonding sites. The monitor photodetectors may be designed to absorb a small fraction of the transmitted and/or received light and convert that fraction of light into a monitor photocurrent for optimizing bias and/or modulation currents to achieve desired operating characteristics of the transmitter and/or an optical link. Such optimization of the bias and/or modulation currents may allow operating characteristics to be adjusted for temperature variations and/or degradation due to aging, optical alignment and/or other environmental factors. Monitoring the transmitted power and/or received power in an optical link may enable health monitoring and/or functions to be implemented in the transceiver. Further, monitoring the transmitted power and/or received power in an optical link may also enable built-in test functions to be implemented in the transceiver.

In another embodiment, a populated optical bench with back-side microlenses for either focusing and/or collimating output/input optical beams is provided. The optical bench apparatus may have a transparent substrate with electrical interconnect lines and/or pads for attaching transmitters and/or receivers by flip-chip bonding. Monitor photodetectors may be aligned to these bonding sites. The monitor photodetectors may be designed to absorb a small fraction of the transmitted and/or received light and convert that fraction of light into a monitor photocurrent for optimizing bias and/or modulation currents to achieve desired operating characteristics of the transmitter and/or an optical link. Such optimization of the bias and/or modulation currents may allow operating characteristics to be adjusted for temperature variations and/or degradation due to aging, optical alignment and/or other environmental factors. Monitoring the transmitted power and/or received power in an optical link may enable health monitoring and/or functions to be implemented in the transceiver. Further, monitoring the transmitted power and/or received power in an optical link may also enable built-in test functions to be implemented in the transceiver.

To this end, an optical bench apparatus is provided. The optical bench apparatus may have a substrate with a first side and a second side. The second side may be located opposite the first side. An optical power monitor photodetector may be integrated on the first side of the substrate. A light

transmitter may have an optical output, and first electrical interconnect lines located on the substrate may permit integrating the light transmitter on the substrate. Second electrical interconnect lines located on the substrate may be connected to the optical power monitor photodetector. The light transmitter may be arranged relative to the optical power monitor photodetector such that the optical output of the light transmitter impinges on the optical power monitor photodetector. The substrate may be transparent to the optical output of the light transmitter.

In an embodiment, the light transmitter may be a light emitting diode (LED), a vertical-cavity surface-emitting laser (VCSEL), a Fabry-Perot laser having an angled mirror for vertical emission, a distributed feedback (DFB) laser having an angled mirror for vertical emission or a DFB laser having a diffraction grating for vertical emission.

In an embodiment, the light transmitter may be integrated by flip-chip bonding.

In an embodiment, the light transmitter may be integrated by die placement.

In an embodiment, the light transmitter may be aligned to allow substantial overlap of the optical output emitted power with the optical power monitor photodetector.

In an embodiment, the substrate may be transparent to the light emitted by the light transmitter.

In an embodiment, the substrate may have one or more lenses formed on the side opposite the light transmitter.

In an embodiment, the lenses may be refractive lenses or diffractive lenses.

In an embodiment, the lenses may collimate the output from the light transmitter.

In an embodiment, the lenses may focus the output from the light transmitter.

In an embodiment, the lenses may steer the output from the light transmitter.

In an embodiment, the substrate may have one or more surfaces anti-reflection coated.

In an embodiment, the electrical interconnect lines may be impedance matched.

In an embodiment, the light transmitter may emit light through the optical power monitor photodetector.

In an embodiment, the optical power monitor photodetector may absorb part of the power emitted by the light transmitter and part of the power may be emitted by the light transmitter may be transmitted through the substrate.

In an embodiment, the optical power monitor photodetector may absorb a portion of the power emitted by the light transmitter.

In an embodiment, the light transmitter may emit light vertically in a first direction away from the substrate and in a second direction into the substrate.

In an embodiment, the light transmitter may emit a first portion of the optical output power away from the substrate and may emit a second portion of the power into the substrate wherein the first portion may be greater than the second portion.

In an embodiment, the monitor photodetector may absorb a portion of the light emitted into the substrate.

In an embodiment, the substrate may be a semiconductor, Gallium Arsenide (GaAs), semi-insulating Gallium Arsenide (GaAs), Aluminum Gallium Arsenide (AlGaAs), Indium Phosphide (InP), silicon, an insulator, sapphire or quartz glass.

In an embodiment, the monitor photodetector may be epitaxially grown.

In an embodiment, the monitor photodetector may be a single crystal semiconductor.

In an embodiment, the monitor photodetector may be a p-i-n photodetector.

In an embodiment, the monitor photodetector may have one or more quantum wells as the absorbing region.

In an embodiment, the monitor photodetector may have one or more absorbing layers of quantum dots.

In an embodiment, the monitor photodetector may be a metal-semiconductor-metal (MSM) photodetector.

In an embodiment, the monitor photodetector may have an absorbing region of Indium Gallium Arsenide (InGaAs).

In an embodiment, the monitor photodetector may be deposited by chemical vapor deposition.

In an embodiment, the monitor photodetector may be a single crystal, polycrystalline, or amorphous material.

In an embodiment, the monitor photodetector may be silicon, germanium, or Indium Gallium Arsenide (InGaAs).

In an embodiment, one or more transmitters may be replaced by one or more receiver photo detectors.

In another embodiment of the invention an optical bench apparatus is provided. The optical bench apparatus may have a substrate having a first side and a second side. The second side may be located opposite the first side. An optical input may be incident on the second side of the substrate. An optical power monitor photodetector may be integrated on the first side of the substrate. The optical bench apparatus may have a photodetector. First electrical interconnect lines may be located on the substrate. The first electrical interconnect lines may permit integrating the photodetector on the substrate. Second electrical interconnect lines located on the substrate may be connected to the optical power monitor photodetector. The photodetector may be aligned with the optical power monitor photodetector such that a portion of the optical input to the photodetector passes through the optical power monitor photodetector. The substrate may be transparent to the optical input.

In an embodiment, the photodetector may be a p-i-n photodetector.

In an embodiment, the photodetector may be a resonant cavity photodetector, an avalanche photodetector or a MSM photodetector.

In an embodiment, the photodetector is integrated by flip-chip bonding.

In an embodiment, the photodetector may be integrated by die placement.

In an embodiment, the photodetector may be aligned to allow substantial overlap of the received optical power with the optical power monitor photodetector.

In an embodiment, the substrate may be transparent to the light received by the photodetector.

In an embodiment, the substrate may have one or more lenses and/or microlenses formed on a back side of the substrate opposite a front side of the substrate having the photodetector.

In an embodiment, the back side microlenses may be aligned to front side devices to form optical beams.

In an embodiment, the microlenses may be refractive and/or diffractive.

In an embodiment, the microlenses may focus and/or collimate the output beams of the transmitters to simplify coupling of the light into optical fibers and/or other optical components.

In an embodiment, the microlenses may focus the incoming beam onto the receiver.

In an embodiment, the microlenses may be designed to collimate the input to the photodetector.

In an embodiment, the microlenses may be designed to focus the input to the photodetector.

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In an embodiment, the microlenses may be designed to steer the input to the photodetector.

In an embodiment, the electrical interconnect lines may be impedance matched.

In an embodiment, the photodetector may receive light through the optical power monitor photodetector.

In an embodiment, the optical power monitor photodetector may absorb part of the incoming power for the photodetector and part of the power for the photodetector may be received through the substrate.

In an embodiment, the optical power monitor photodetector may absorb a portion of the power for the photodetector.

In a further embodiment, a method of monitoring optical power is provided. The method may have the steps of providing an optical bench apparatus having a substrate with electrical interconnect lines; integrating an optical power monitor photodetector with the substrate wherein the electrical interconnect lines connect the optical power monitor photodetector; integrating a light transmitter with the substrate wherein the electrical interconnect lines connect the light transmitter and further wherein the light transmitter has an optical output; and aligning the optical output of the light transmitter relative to the optical power monitor photodetector such that the optical output of the light transmitter impinges on the optical power monitor photodetector.

In an embodiment, the method may have the step of optimizing bias and/or modulation currents to achieve desired operating characteristics of the transmitter.

In an embodiment, the method may have the step of optimizing bias and/or modulation currents to achieve desired operating characteristics of an optical link.

In an embodiment, the method may have the step of adjusting operating characteristics of the transmitter for temperature variations by optimizing bias and/or modulation currents.

In an embodiment, the method may have the step of adjusting operating characteristics of the transmitter for degradation by optimizing bias and/or modulation currents.

In an embodiment, the method may have the step of implementing health monitoring in a transceiver by monitoring the transmitted power and/or received power in an optical link.

In an embodiment, the method may have the step of implementing built-in test functions in a transceiver by monitoring the transmitted power and/or received power in an optical link.

In yet another embodiment, a method of monitoring optical power is provided. The method may have the step of providing an optical bench apparatus having a substrate and an integrated optical power monitor photodetector. The method may have the step of providing electrical interconnect lines on the substrate. The method also may have the steps of integrating a photodetector with the electrical interconnect lines to the optical bench apparatus and connecting the monitor photodetectors with the electrical interconnect lines to the optical bench apparatus. The method may have the step of aligning the input of the photodetector such that the input of the photodetector overlaps with the monitor photodetector.

An advantage of the invention may be to provide an optical bench apparatus in which a smaller, faster photodetector may be used.

Another advantage of the invention may be to provide an optical bench apparatus to improve alignment tolerances.

A further advantage of the invention may be to provide an optical bench apparatus having one or more lenses formed

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on the side opposite the light transmitter. The lenses may be refractive and/or diffractive. The lenses collimate the output from the light transmitter, focus the output from the light transmitter and/or steer the output from the light transmitter.

Another advantage of the invention may be to provide a method of monitoring optical power having the step of optimizing bias and/or modulation currents to achieve desired operating characteristics of the transmitter and/or an optical link.

Yet another advantage of the invention may be to provide a method having the step of adjusting operating characteristics of the transmitter for temperature variations and/or degradation by optimizing bias and/or modulation currents.

Still another advantage of the invention may be to provide a method having the step of implementing health monitoring and/or built-in test functions in a transceiver by monitoring the transmitted power and/or received power in an optical link.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of an embodiment of an optical bench having a transparent substrate with electrical interconnect lines and/or flip-chip bonding bumps aligned to monitor photodetectors.

FIG. 2 is a schematic diagram of an embodiment of an optical bench with monitor photodetectors.

FIG. 3 is a schematic diagram of an embodiment of a populated optical bench with back-side microlenses for focusing and/or collimating output/input optical beams.

## DETAILED DESCRIPTION OF THE INVENTION

In an embodiment of the invention, an optical bench apparatus may have a transparent substrate with electrical interconnect lines and/or pads for attaching transmitters and/or receivers by flip-chip bonding. Aligned to these bonding sites may be monitor photodetectors that may be designed to absorb a small fraction of the transmitted and/or received light and convert it into a monitor photocurrent for optimizing bias and/or modulation currents to achieve desired operating characteristics of the transmitter and/or an optical link.

Referring now to the Figures where like numerals indicate like elements, a schematic diagram of an embodiment of the optical bench apparatus is shown in FIG. 1. In particular, FIG. 1 schematically illustrates an optical bench apparatus 10 having a transparent substrate with electrical interconnect lines 20 for monitor photodetectors and/or bonding sites 30 for attaching transmitters (see FIGS. 2 and 3) and/or receivers (see FIGS. 2 and 3) by flip-chip bonding, for example. In an embodiment, the bonding sites 30 may be bonding bumps and/or pads. Monitor photodetectors 40 may be aligned to the bonding sites 30.

The monitor photodetectors 40 may be designed to absorb a small fraction of the transmitted light and/or the received light. Further, the monitor photodetectors 40 may be designed to convert the fraction of the light into a monitor photocurrent. The monitor photocurrent may be utilized for optimizing bias and/or modulation currents to achieve desired operating characteristics of the transmitter and/or an optical link. Such optimization of the bias and/or modulation currents may allow operating characteristics to be adjusted for temperature variations and/or degradation due to aging, optical alignment and/or other environmental factors. Monitoring the transmitted power and/or received power in an



optical link may enable health monitoring and/or functions to be implemented in the transceiver. Further, monitoring the transmitted power and/or received power in an optical link may also enable built-in test functions to be implemented in the transceiver.

Further, the optical bench apparatus **10** may have the substrate **100** with the monitor photodetectors **40** on the front side. The monitor photodetectors **40** may be aligned with the flip-chip bonding bumps **30** such that the light emission of the transmitters, the VCSELs **50** and/or the Light Emitting Diodes (LEDs) **60**, after flip-chip bonding, may be aligned with the monitor photodetectors **40**. Thus, the light emission of the transmitters may pass through the monitor photodetectors **40** with a portion of the transmitted light absorbed by the monitor photodetectors **40**. The monitor photodetectors **40** may have a thin absorption region, preferably quantum wells, such that the percentage of light absorbed may be relatively small, providing sufficient photocurrent to monitor the transmitted power, but small enough to have a minimal effect of the transmitted power.

As shown in FIGS. **2** and **3**, the transmitters may be VCSELs **50** and/or LEDs **60** and/or other suitable light transmission devices. For example, the transmitters may also be a Fabry-Perot laser having an angled mirror for vertical emission, a distributed feedback (DFB) laser having an angled mirror for vertical emission or a distributed feedback (DFB) laser having a diffraction grating for vertical emission. One having ordinary skill in the art may recognize that other types of light transmitters may be suitable for the present invention. Thus, this disclosure is not limited to a particular light transmitter and all suitable light transmitters are considered to be within the scope of this disclosure.

The receivers may be a variety of different types of photodetectors **70**, for example, p-i-n photodetectors, single and/or multiple quantum well photodetectors, resonant cavity photodetectors, MSM photodetectors, avalanche photodetectors, phototransistors and/or photoconductors. The monitor photodetectors **40** may be single and/or multiple quantum well photodetectors, quantum dot photodetectors, and/or p-i-n photodetectors. The monitor photodetectors **40** and/or the photodetectors **70** may have absorbing regions consisting of a variety of materials including single crystal, polycrystalline, and/or amorphous semiconductors. The monitor photodetectors **40** may be biased or unbiased. One having ordinary skill in the art may recognize that other types of photodetectors may be suitable for the present invention. Thus, this disclosure is not limited to a particular photodetector and all suitable photodetectors are considered to be within the scope of this disclosure.

The transmitters, such as the VCSEL **50**, and/or the receivers, such as the photodetector **70**, for example a p-i-n photodetector, may be flip-chip bonded in any combination and/or number with the monitor photodetectors **40** included on at least one site, but not necessarily all of the sites. The light transmitters may also be integrated by die placement. Further, the optical power monitor photodetector **40** may be epitaxially grown or may be deposited by chemical vapor deposition.

FIG. **2** is a schematic of another embodiment of an optical bench populated with the VCSEL **50** and/or the photodetector **70**. In particular, FIG. **2** illustrates the optical bench **10**. Each bond site **30** may be populated with the VCSEL **50** and/or the LED **60** fabricated on a substrate **65** for the transmitter and/or the photodetector **70** fabricated on a substrate **75** for the receiver. As shown in FIG. **2**, an outgoing optical beam, optical output **80** and/or an incoming optical beam, optical input **90**, may pass through the respec-

tive monitor photodetector **40** and/or a substrate **100**. The monitor photodetector **40** may absorb a small fraction of the transmitted optical power and may convert the small fraction of light into a monitor photocurrent. In an embodiment, the substrate **100** may be transparent. Further, the substrate **100** may have a surface having an anti-reflection coating (not shown).

FIG. **3** is a schematic of another embodiment of the optical bench **10** populated with the VCSEL **50** and/or the LED **60** and/or the photodetector **70**. Each bond site **30** may be populated with the VCSEL **50** and/or the LED **60** for the transmitter and/or the photodetector **70** for the receiver. In the embodiment illustrated in FIG. **3**, the optical bench **10** may also have microlenses **110** located on the substrate **100**. As shown, the microlenses **110** may be arranged on a back side of the substrate **100** opposite to a front side of the substrate **100** having the monitor photodetectors **40**. The microlenses **110** may also be aligned to front side devices such as, for example, optical fibers and/or other optical components (not shown) to form optical beams. For example, the microlenses **110** may form the optical beams of the optical output **80** and/or the optical beams of the optical input **90**. The microlenses **110** may be either refractive and/or diffractive. For the transmitters, such as the VCSELs **50** and/or the LEDs **60**, the microlenses **110** may focus and/or collimate the outgoing beam of the output beam **80** to simplify coupling of the light into optical fibers and/or other optical components (not shown). For the receivers, such as the photodetector **70**, the microlenses **110** may focus the incoming beam of the optical input **90** onto the receiver **70**. In an embodiment of the invention, the use of the microlenses **110** may enable a smaller and/or faster photodetector **70** to be used. Also, the use of the microlenses **110** in this manner may improve the alignment tolerances of the optical bench apparatus **10**.

The optical bench apparatus **10** may be utilized to implement a method of monitoring optical power in an optical link. For example, the method may have the step of providing an optical bench apparatus **10** having the substrate **100** with the electrical interconnect lines **20**. The method may have the step of integrating the optical power monitor photodetector **40** with the substrate **100**. The electrical interconnect lines **20** may connect the optical power monitor photodetector **40**. The method may also have the step of integrating the light transmitter, for example, the VCSEL **50** and/or the LED **60** with the substrate **100**. The electrical interconnect lines **20** may connect the light transmitter. The light transmitter may have the optical output **80**. Finally, the method may have the step of aligning the optical output **80** of the light transmitter relative to the optical power monitor photodetector **40** such that the optical output **80** of the light transmitter impinges on the optical power monitor photodetector **40**.

The method may have additional steps to monitor optical power in an optical link. For example, the method may have the step of optimizing bias and modulation currents to achieve desired operating characteristics of the light transmitter. Further, the method may have the step of optimizing bias and modulation currents to achieve desired operating characteristics of the optical link. Also, the method may have the step of adjusting operating characteristics of the light transmitter for temperature variations by optimizing bias and/or modulation currents. Moreover, the method may have the step of adjusting operating characteristics of the transmitter for degradation by optimizing bias or modulation currents. In addition, the method may have the step of implementing health monitoring in a transceiver by moni-

toring transmitted power or received power in the optical link. Finally, the method may have the step of implementing built-in test functions in a transceiver by monitoring transmitted power or received power in the optical link.

In summary, the monitor photocurrent may be utilized for optimizing bias and/or modulation currents to achieve desired operating characteristics of the transmitter and/or an optical link. Such optimization of the bias and/or modulation currents may allow operating characteristics to be adjusted for temperature variations and/or degradation due to aging, optical alignment and/or other environmental factors. Monitoring the transmitted power and/or received power in an optical link may enable health monitoring and/or functions to be implemented in the transceiver. Further, monitoring the transmitted power and/or received power in an optical link may also enable built-in test functions to be implemented in the transceiver.

It should be understood that various changes and/or modifications to the presently preferred embodiments described herein will be apparent to those having ordinary skill in the art. Such changes and/or modifications may be made without departing from the spirit and/or scope of the present invention and without diminishing its attendant advantages. It is, therefore, intended that such changes and/or modifications be covered by the appended claims.

I claim:

1. An optical bench apparatus comprising:
  - a substrate having a first side and a second side, wherein the second side is located opposite the first side;
  - an optical power monitor on the first side of the substrate;
  - a photodetector configured to detect an optical input that passes through the substrate and the optical power monitor;
  - first group of electrical interconnect lines located on the substrate, wherein the first electrical interconnect lines are configured to connect to the photodetector;
  - second group of electrical interconnect lines located on the substrate and configured to connect to the optical power monitor; and
  - a bonding site on the substrate configured to bond to the photodetector, wherein the bonding site is located to optically align the photodetector with the optical power monitor such that the optical input received through the substrate impinges on the optical power monitor,
 wherein the optical power monitor is configured to receive the optical input that passes through the substrate and absorb a portion of the received optical input so that the portion of the optical input received by the photodetector is less than all of the optical input that passes through the substrate.
2. The apparatus of claim 1, wherein the optical power monitor is configured to transmit the optical input that passes through the substrate.
3. The apparatus of claim 1, wherein the substrate is configured to transmit a first portion of the optical input, and wherein the optical power monitor is configured to absorb a second portion of the optical input.
4. The apparatus of claim 1, further comprising: a lens on the second side of the substrate opposite the photodetector, wherein the lens is configured to collimate, focus, or steer the optical input.
5. The apparatus of claim 1, wherein the substrate has a surface having an anti-reflection coating.
6. The apparatus of claim 1, wherein the first and second groups of electrical interconnect lines are impedance matched.

7. The apparatus of claim 1, wherein the substrate includes a semiconductor, Gallium Arsenide (GaAs), semi-insulating Gallium Arsenide, Aluminum Gallium Arsenide (AlGaAs), Indium Phosphide (InP), silicon, an insulator, sapphire or quartz glass.

8. The apparatus of claim 1, wherein the light transmitter includes a light emitting diode (LED), a vertical-cavity surface-emitting laser (VCSEL), a Fabry-Perot laser having an angled mirror for vertical emission, a distributed feedback (DFB) laser having an angled mirror for vertical emission, or a distributed feedback (DFB) laser having a diffraction grating for vertical emission.

9. The apparatus of claim 1, wherein the optical power monitor includes a single crystal semiconductor, a polycrystalline material, an amorphous material, silicon, germanium, Indium Gallium Arsenide (InGaAs), a p-i-n photodetector, or a metal-semiconductor-metal (MSM) photodetector.

10. The apparatus of claim 1, wherein the optical power monitor has an absorbing region, wherein the absorbing region includes a bulk material, quantum well, or quantum dots.

11. The apparatus of claim 1, wherein the bonding site configured to bond to the photodetector includes a flip-chip bond or by die placement.

12. The apparatus of claim 1, wherein the optical power monitor and the photodetector are integrated on the substrate.

13. An optical bench apparatus comprising:
 

- a photodetector configured to detect an optical signal;
- a substrate configured to transmit at least a portion of the optical signal;
- an optical power monitor disposed on the substrate, wherein the optical power monitor is configured to receive the optical signal transmitted by the substrate and absorb a portion of the received optical signal so that less than all of the optical signal arrives at the photodetector;
- a first group of electrical interconnect lines located on the substrate to connect to the photodetector; and
- a second group of electrical interconnect lines located on the substrate to connect to the optical power monitor; and
- a receiver substrate including a photodetector electrically connected to the substrate to align the photodetector with the optical power monitor so that the photodetector and the optical power monitor detect the optical input transmitted through the substrate.

14. The apparatus of claim 13, wherein the photodetector is configured to receive the optical input through the optical power monitor photodetector.

15. The apparatus of claim 13, wherein the optical power monitor photodetector is configured to absorb a first part of the optical input, and wherein the photodetector is configured to receive a second part of the optical input.

16. The apparatus of claim 13, further comprising:
 

- a lens disposed on the substrate to collimate, focus or steer the optical input to the photodetector.

17. The apparatus of claim 16, wherein the lens includes a refractive lens, or a diffractive lens.

18. The apparatus of claim 13, comprising:
 

- an anti-reflection coating on a surface of the substrate.

19. The apparatus of claim 13, wherein the first and second groups of electrical interconnect lines are impedance matched.

20. The apparatus of claim 13, wherein the substrate includes a semiconductor, Gallium Arsenide (GaAs), semi-

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insulating Gallium Arsenide, Aluminum Gallium Arsenide (AlGaAs), Indium Phosphide (InP), silicon, an insulator, sapphire, or quartz glass.

21. The apparatus of claim 13, wherein the photodetector includes a p-i-n photodetector, a resonant cavity photodetector, an avalanche photodetector, or a metal-semiconductor-metal (MSM) photodetector.

22. The apparatus of claim 13, wherein the receiver substrate that includes the photodetector is connected to the substrate by flip-chip bonding or by die placement.

23. The apparatus of claim 13, wherein the optical power monitor is integrated on the substrate.

24. A method of monitoring optical power in an optical link comprising:

detecting, by an optical power monitor aligned with a photodetector in an optical bench apparatus, an optical input that impinges on the optical power monitor, the optical power monitor being disposed on a substrate, the photodetector being connected to a first group of electrical interconnect lines located on the substrate and the optical power monitor being connected to a second group of electrical interconnect lines located on the substrate;

absorbing, by the optical power monitor, a fraction of the detected optical input so that less than all of the optical input reaches the photodetector;

converting, by the optical power monitor, the absorbed fraction of the detected optical input into a monitor photocurrent; and

monitoring the optical power of the detected optical input based on the monitor photocurrent.

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25. The method of claim 24, further comprising: adjusting bias and modulation currents to achieve desired operating characteristics of the optical link.

26. The method of claim 24, further comprising: implementing health monitoring in a transceiver by monitoring received power in the optical link.

27. The method of claim 24, further comprising: implementing built-in test functions in a transceiver by monitoring received power in the optical link.

28. A method of manufacturing an optical bench apparatus, comprising:

providing an optical bench apparatus having a substrate and an integrated optical power monitor;

aligning a photodetector with the optical power monitor such that an optical input is transmitted through the optical power monitor to impinge on the photodetector;

connecting the photodetector to a first group of electrical interconnect lines provided on the substrate;

connecting the optical power monitor with a second group of the electrical interconnect lines provided on the substrate;

wherein the optical power monitor is integrated with the substrate and is configured to absorb a portion of the optical input so that less than all of the optical input is transmitted through the substrate.

29. The method of claim 28, comprising:

epitaxially growing the optical power monitor.

30. The method of claim 28, further comprising integrating the photodetector with the first group of electrical interconnect lines in the optical bench apparatus.

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